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Retrospective Dose Assessment for the Population Living in Areas of Local Fallout from the Semipalatinsk Nuclear Test Site Part II: Internal Exposure to Thyroid

Konstantin GORDEEV[1], Sergey SHINKAREV[2*], Leonid ILYIN[2], André BOUVILLE[3], Masaharu HOSHI[4], Nickolas LUCKYANOV[3] and Steven L. SIMON[3]

Semipalatinsk test site/Retrospective assessment/Internal exposure/Radioiodine/Thyroid.

A methodology to assess internal exposure to thyroid from radioiodines for the residents living in settlements located in the vicinity of the Semipalatinsk Nuclear Test Site is described that is the result of many years of research, primarily at the Moscow Institute of Biophysics. This methodology introduces two important concepts. First, the biologically active fraction, is defined as the fraction of the total activity on fallout particles with diameter less than 50 microns. That fraction is retained by vegetation and will ultimately result in contamination of dairy products. Second, the relative distance is derived as a dimensionless quantity from information on test yield, maximum height of cloud, and average wind velocity and describes how the biologically active fraction is distributed with distance from the site of the explosion. The parameter is derived in such a way that at locations with equal values of relative distance, the biologically active fraction will be the same for any test. The estimates of internal exposure to thyroid for the residents of Dolon and Kanonerka villages, for which the external exposure were assessed and given in a companion paper (Gordeev *et al.* 2006) in this conference, are presented. The main sources of uncertainty in the estimates are identified.

INTRODUCTION

Dosimetry support of an ongoing epidemiological study conducted by the U.S. National Cancer Institute in Kazakhstan includes individual thyroid dose reconstruction for about 3,000 residents of eight settlements located near the Semipalatinsk Test Site (STS) with different levels of exposures. The total dose to thyroid consists of two components external and internal (mainly from radioiodines accumulated in the thyroid). Paper[1)] considers the methodology and results of external dose to the thyroid for the residents of Dolon and Kanonerka villages. Those villages were selected in order to make a comparison of the estimates of external dose to the residents based on single historical measurements and derived from thermoluminescence measurements in bricks obtained from local buildings and electron paramagnetic resonance measurements in teeth taken from local residents. Dolon and Kanonerka were heavily exposed due to event #1 exploded on August 29, 1949 and residents born in 1935 (14 y old in 1949) were selected for dose assessment in a companion paper.[1)]

This paper presents the methodology and results of assessment of internal dose to thyroid from radioiodines for the population of the same two villages. In order to be consistent with a companion paper[1)] the residents of the same age are considered here. Comparison of internal and external doses to thyroid is discussed. In addition, some strengths and weaknesses of the described methodology are indicated.

MATERIALS AND METHODS

A detailed description of the methodology to assess thyroid dose from internal exposure to radioiodines is given previously.[2)] The main issues of that methodology are described in this paper. Similar to assessment of external dose[1)] the methodology of assessment of internal dose to thyroid consists of two steps. In the first step the radiological

*Corresponding author: Phone: +7-495-190-9687,
Fax: +7-495-190-3590,
E-mail: sshinkarev@atom.ru
[1]State Research Center Institute of Biophysics, Ministry of Public Health and Social Development, 46 Zhivopisnaya Street, Moscow 123182, Russian Federation (deceased); [2]State Research Center Institute of Biophysics, Ministry of Public Health and Social Development, 46 Zhivopisnaya Street, Moscow 123182, Russian Federation; [3]Division of Cancer Epidemiology and Genetics, National Cancer Institute, NIH, DHHS, 6120 Executive Boulevard (EPS 7094), Rockville, MD 20852, USA; [4]Research Institute for Radiation Biology and Medicine, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8557, Japan

conditions in a settlement located in the area of local fallout are reconstructed. In the second step the dose assessment for the population groups living at the location of interest is carried out based on the reconstructed radiological conditions taking into account their lifestyle and dietary habits.

To reconstruct parameters of the radiological conditions that pertain to assessment of internal dose to thyroid, the same input data (as for external exposure[1)]) are used in the model:

- type and composition of fission material;
- date and time of explosion;
- height of radioactive cloud top (km);
- height of detonation above ground surface (m); and
- average wind speed over the height of the radioactive cloud (km h^{-1}).

The main parameters characterizing the radiological conditions at the location of interest and used in the assessment of internal dose to thyroid derived from the model are as follows:

- fallout arrival time, H+t (h);
- duration of fallout Δt (h);
- fraction of the activity of the radionuclides in fallout assigned to the biologically active particles with diameter $d \leq 50$ µm, $\eta_{d \leq 50}$ (dimensionless);
- average concentration of radionuclides in ground-level air during the time of radioactive fallout (Bq m^{-3});
- radionuclide ground deposition density at time H+24 h, $\sigma_{\Sigma,24}$ (Bq m^{-2});
- exposure rate at time H+24 h, P_{24} (mR h^{-1}).

To assess internal thyroid dose to the residents based on the reconstructed radiological conditions the following parameters accounting for lifestyle and dietary habits are used:

- age-dependent breathing rates;
- type of milk consumed;
- age-dependent milk consumption rates.

It is necessary to stress that two important concepts were introduced in the methodology:[2)]

(1) "Biologically active fraction", defined as the fraction of the total activity on fallout particles with diameter less than 50 microns. That fraction is retained by vegetation and will ultimately result in contamination of dairy products.

(2) "Relative distance" derived as a dimensionless quantity from the parameters of an event and meteorological data. It describes how the biologically active fraction is distributed with distance from the site of the explosion. At locations with equal values of relative distance, the biologically active fraction will be the same for any test.

The biologically active fraction, $\eta_{d\leq 50}$, of fallout is estimated according to the following equation:

$$\eta_{d\leq 50} = 1 - [1 - 0.6 \times (h_{max} \times V_{av})^{-0.9}] \times \exp(-4 \times X_r^3) \quad (1)$$

where

$\eta_{d\leq 50}$ is the biologically active fraction of fallout, dimensionless;

h_{max} is the height of the radioactive cloud top, km;

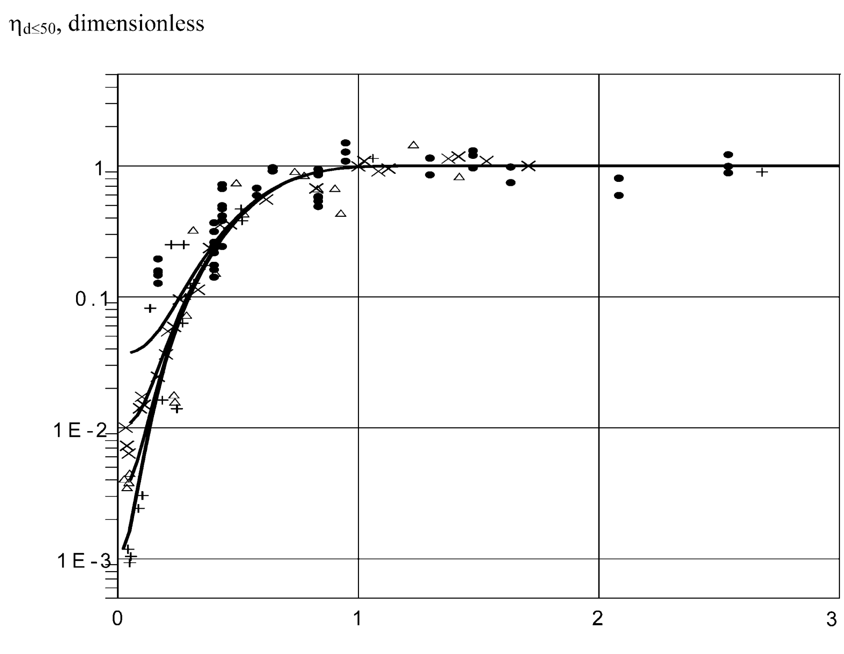

Fig. 1. Variation of biologically active fraction with relative distance. Fitting of experimental data received for various nuclear events conducted at the Semipalatinsk Test Site.

Table 1. Input data[4] related to characteristics of the radiological conditions that pertain to assessment of thyroid dose from internal exposure following the most significant events for the residents of Dolon and Kanonerka villages.

Settlement	Event		Time of arrival of fallout, H+t, h	Duration of fallout Δt, h	Biologically active fraction of fallout, $\eta_{d\leq 50}$	Average activity concentration in ground –level air during fallout, Bq m^{-3}	Ground deposition density at time H+24 h, $\sigma_{\Sigma,24}$, Bq m^{-2}	Exposure rate at H+24 h, P_{24}, mR h^{-1}
	Date	Number						
Dolon	29.08.49	1	2.4	2.0	0.03	$5.5 \cdot 10^{8}$	$4.3 \cdot 10^{9}$	1150
	29.07.55	19	3.1	2.1	0.3	$2.0 \cdot 10^{5}$	$1.9 \cdot 10^{6}$	0.5
	7.08.62	148	10.5	7.6	1.0	$1.2 \cdot 10^{5}$	$3.7 \cdot 10^{6}$	1.0
Kanonerka	29.08.49	1	3.0	2.4	0.06	$9.7 \cdot 10^{7}$	$9.3 \cdot 10^{8}$	250
	29.07.55	19	4.2	2.8	0.58	$1.8 \cdot 10^{5}$	$2.2 \cdot 10^{6}$	0.6
	7.08.62	148	13.2	9.4	1.0	$9.1 \cdot 10^{4}$	$3.7 \cdot 10^{6}$	1.0

V_{av} is an average wind speed over the height of the radioactive cloud, km h^{-1}; and

X_r is a relative distance, dimensionless.

The values of relative distance, X_r, are calculated according to the ratio:

$$X_r = (X \times W_{50}) / (h_{max} \times V_{av}) \quad (2)$$

where

X is a current distance along the trace axis, km; and

W_{50} is a sedimentation velocity for fallout particles of 50 μm; it is assumed to be equal to 0.73 km h^{-1} for soil types typical for the STS.

Empirical dependence of biologically active fraction of fallout versus relative distance was derived from fitting of experimental data received for various nuclear events conducted at the STS (see Fig. 1).

The above methodology was used for preliminary assessment of thyroid dose from internal exposure to radioiodines for the cohort members of an ongoing epidemiological study in Kazakhstan.[3] Below is an example of application of the methodology to the residents of Dolon and Kanonerka villages (the same settlements that were considered in a companion paper related to external exposure[1]). Table 1 gives the input data[4] related to characteristics of the radiological conditions in the villages that pertain to assessment of thyroid dose from internal exposure following the most significant events. The same group of residents born in 1935[1] (14 y in 1949) were selected to assess internal dose to thyroid. Radioiodine intake with cow's milk was the main pathway for the residents of Dolon and Kanonerka. It is assumed that cows were on pasture during a time period of a few weeks after each test and that only milk of local origin was consumed. Under those conditions, the contributions of other foodstuffs, e.g., leafy vegetables or meat, to the thyroid doses from internal irradiation are minor; hence, they have not been considered in the calculations. Thus, only intakes of radioiodines via inhalation and ingestion with cow's milk were accounted for. The thyroid doses from internal irradiation were calculated for: (1) inhalation intake of ^{131}I, ^{133}I, and ^{135}I and (2) ingestion intake with milk of ^{131}I and ^{133}I. The breathing rates were taken from ICRP 66;[5] while the milk consumption rate was assumed to be 0.7 L d^{-1} for all events. The values of the thyroid dose coefficients were taken from elsewhere.[6]

RESULTS AND DISCUSSION

An example of thyroid dose estimates from internal exposure for the considered residents of Dolon and Kanonerka, assuming that no countermeasures were taken, are presented in Table 2. According to[7] the main contributor (about 89%) to thyroid dose from ingestion intake of cow's milk was ^{131}I. In addition, the estimates of external exposure to the same residents taken from[1] are presented in Table 2 for the purpose of comparison of external and internal doses to thyroid. The last column in Table 2 shows the ratio of dose to thyroid from internal to external exposures for the residents born in 1935. This ratio varies greatly from about 1 to 30 for both villages depending upon the event under consideration. It is worth noting that for the most important event #1, which resulted in the heaviest contamination of both villages the internal and external doses to thyroid are estimated to be very close to each other, while for event #148 which resulted in much less contamination this ratio is estimated to be 32 in favor of internal dose. This is due to a physical phenomenon, that only fallout particles less than 50 microns are intercepted and reliably retained by vegetation, because only about 3% for Dolon and 6% for Kanonerka of total deposited activity following event #1 are estimated to be on the fallout particles with diameter less than 50 microns. Thus, only small amounts of deposited activity reached residents in these villages through cow's milk.

In the companion paper[1] it was concluded that the estimate of external dose (1.2 Sv) for the residents in Dolon fol-

Table 2. An example of thyroid dose estimates from internal exposure for the residents born in 1935 of Dolon and Kanonerka villages, assuming that no countermeasures were taken, versus external dose to thyroid.

Settlement	Event		Internal absorbed dose to thyroid, mGy			External whole-body dose[1)], mGy	Ratio of internal to external dose to thyroid, dimensionless
	Date	Number	Inhalation	Ingestion	Total		
Dolon	29.8.49	1	10	1050	1060	1240	0.85
	29.7.55	19	0.06	3.5	3.6	0.7	5.1
	7.8.62	148	1.9	33	35	1.1	32
Kanonerka	29.8.49	1	5.8	440	450	250	1.8
	29.7.55	19	0.2	8.5	8.7	0.8	11
	7.8.62	148	2.4	33	35	1.1	32

lowing event #1 should be considered as a possible maximum individual dose rather than the average dose to the population. With respect to thyroid dose due to the consumption of milk contaminated with ^{131}I and ^{133}I it is difficult to assess the reliability of the presented estimates, because they cannot be confirmed by any present-day measurement. Moreover, the dose estimates depend on highly uncertain parameters including the fraction of fallout debris intercepted by plants, the solubility of fallout of different particles sizes and at different locations, sites where cows consumed pasture grass during a few weeks following the event if the distribution of fallout was not uniform (as the case with Dolon following event #1),[8,9] transfer coefficients for different types of dairy animals, and the origin and amount of milk consumed by each person. In addition, it is worth noting that despite the overall concept of the presented methodology reflecting the actual physics for close-in distances, i.e. that generally only smaller particles are intercepted and retained by vegetation and that heavier particles fall out faster and thus at closer distances than smaller particles, the methodology has a number of weaknesses. For example, the estimates of the biologically active fraction of fallout are related to the axis of the fallout pattern, while these values should be raised with increasing off-axis distance. Also, in the methodology the effects of fractionation are generally neglected, whereas they should be accounted for.

It is important to note that the methods and estimates of internal exposure to the cohort members included into the epidemiological study conducted by the U.S. National Cancer Institute in the Republic of Kazakhstan are being revised. The preliminary estimates of internal thyroid dose that are given in this paper will be improved.

CONCLUSIONS

1. The ratio of internal to external doses to thyroid for the rural population permanently residing in a settlement contaminated due to a surface event strongly depends (being more than one order of magnitude higher) upon the fraction of the total activity on fallout particles with diameter less than 50 microns.
2. Dependence of the biologically active fraction of fallout versus relative distance considered in the methodology is related to the axis of the radioactive trace. There is also a dependence on the off-axis distance and this fraction increases with an increase of the off-axis distance.
3. The methodology and the estimates of thyroid dose presented above are preliminary. They were used at an initial phase of an ongoing epidemiological study conducted by the NCI in Kazakhstan. The U.S./Russian joint methodology that is being developed will lead to a revised set of dose estimates.

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